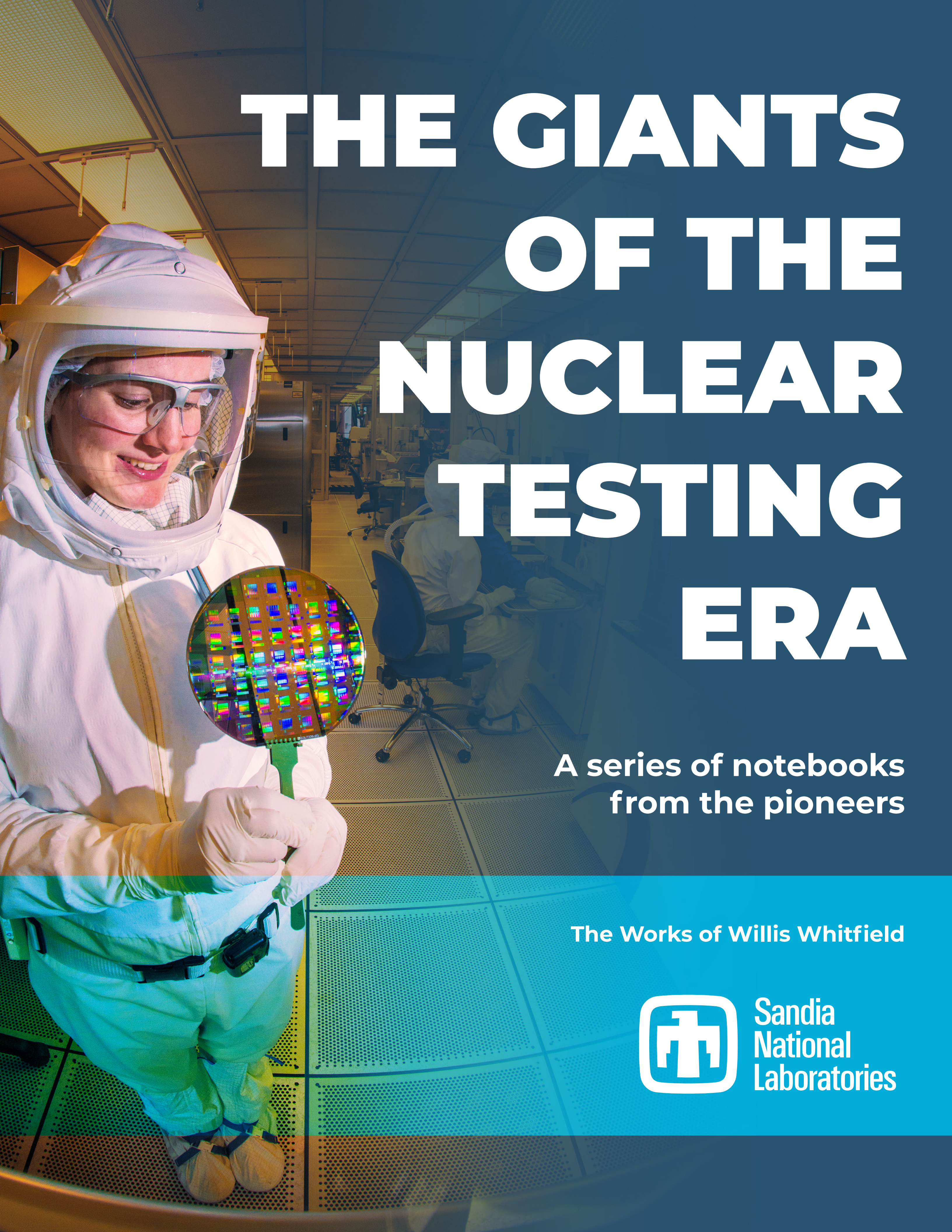


# THE GIANTS OF THE NUCLEAR TESTING ERA

A series of notebooks from the pioneers

The Works of Willis Whitfield

Sandia National Laboratories

This work is part of a series sponsored by the Archiving Data and Management (ADAM) program within the National Nuclear Security Administration's Office of Engineering Stockpile Assessments and Responsiveness (NA-115). The ADAM program is responsible for preserving the data and irreplaceable knowledge from the nuclear weapons testing era. This information continues to be used to support the current and future stockpile and also train the next generation of weapons scientists with no nuclear testing experience.

# THE GIANTS OF THE NUCLEAR TESTING ERA

## A series of notebooks from the pioneers

### The Works of Willis Whitfield

Sandia National Laboratories

# PREFACE

In 1959, Sandia Laboratory[1] had a problem. Multiple lots of hand-assembled coded switches manufactured by U.S. Gauge in Pennsylvania were failing to meet quality standards. Particulates in the assembly areas were contaminating the parts. The devices' tolerances were so close that they would not work with the least bit of contamination.

This was not an unusual problem in industry, but Sandia had oversight for production of the non-nuclear components for nuclear weapons. It was the height of the Cold War and multiple weapon designs were due to enter the U.S. stockpile. Thus, the Lab's advanced manufacturing engineering organization set out to solve the problem.

Willis Whitfield joined Sandia as a staff member in 1954. Before arriving, he received a BS in physics and mathematics from Hardin Simmons University and served as a division head at the Naval Research Laboratory while taking graduate courses at George Washington University. In 1958, he moved to the advanced manufacturing section at Sandia responsible for solving problems in production engineering.

When his group began investigating the contamination issue, Whitfield volunteered. He and other Sandia staff visited U.S. Gauge and other manufacturers to understand the problem. They informed themselves of the standards in clean room design and traveled to different industrial facilities to view recent clean room installations. They collected information on design and operational details, as well as methods for sampling and obtaining dust counts within the facilities. They attended and gave papers at conferences on dust control. Ultimately, they determined that, in general, the ability to control airborne contamination was not sufficient to meet the needs of modern manufacturing, particularly the fabrication of electro-mechanical systems.

Standard practice at the time was to use tightly sealed stainless steel clean rooms, maintain strict garmenting requirements for all workers, use furniture and equipment that was easily cleaned, and clean the space frequently. One of the best clean rooms of the period averaged more than a million particles per cubic foot of air. The cleanest air hoods attained a level of approximately 100,000 particles of 0.5 micron and larger per cubic foot. Care was taken not to clean too often, lest equipment and surfaces be damaged by the effort. The focus was on keeping contaminants out, not on removing any generated by the work or personnel inside the room.

Whitfield is known for transforming clean room design. Not just improving it or advancing it, but introducing a concept that resulted in an environment 1000 times cleaner than any design before it. The idea was simple—shift the focus from keeping contaminants out to using clean, filtered air to continually remove any particulates that got into or were generated in the space. This eliminated contamination instead of just controlling it, and it solved the nuclear weapon component manufacturing problem. The consistent air flow ultimately resulted in calling the new design the "laminar air flow clean room."

Whitfield did not work alone. Other personnel in the manufacturing development groups also researched the problem and participated in the design of the improved clean rooms, benches, and hoods, as well as contamination monitoring technology. Key individuals in the work at Sandia were Claude Marsh, James McDowell, James Mashburn, William Neitzel, Irving Kodel, Longinos Trujillo, and Harold Baxter.

1 The name of the institution has changed over time. Sandia Laboratory was renamed Sandia Laboratories in 1969 and was re-designated Sandia National Laboratories via legislation passed in 1979. It will be referred to as Sandia throughout the remainder of this document.

2

12-28-60 Ideal Clean Room Design
(Proposed)

This experimental room is six feet wide, ten feet long and ceiling height of 7 ft. Work bench is 24" x 10 ft, covered with stainless steel or formica. Ordinary steel, padded stool with plates installed on stool legs to provide level footing on grated floor.

The construction of this room is similar to other clean rooms in wall ceiling and structural design. The main difference in this design as compared to other clean rooms, are the floor and filtration system. The floor is constructed of steel grating under which is located the "rough" filters. The absolute ~~filters~~ filter is located as a part of the clean room wall ~~is~~ (as shown) in shelf ~~f~~ or pleated form to provide the req'd air flow capty. The filter is held in position by stainless steel fixtures located above work area. Extra thermal insulation, double window glass and lights located outside clean area are provided to reduce heat load on air conditioner system.

This room is designed to overcome these disadvantages in present clean room design by:

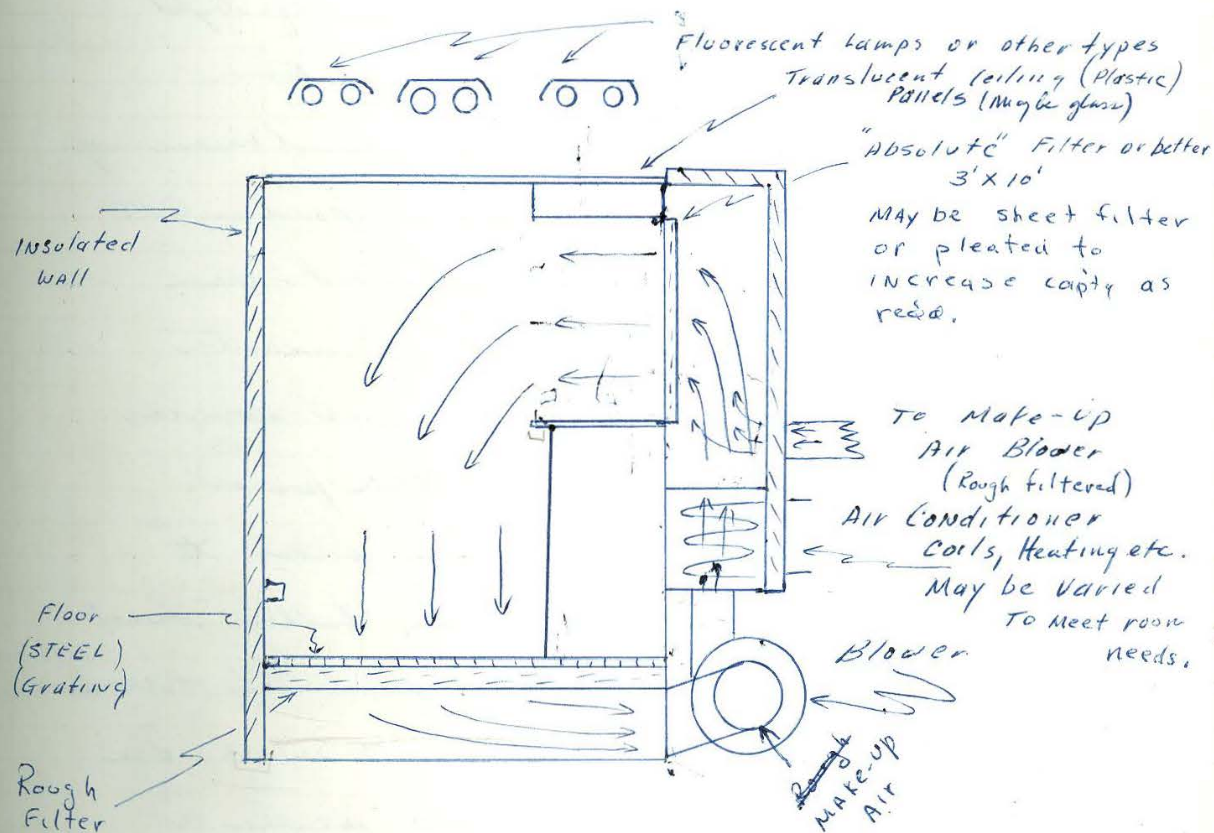
1. Provide clean air flow in sufficient quantity and flow pattern to carry contaminants away from clean area and to provide almost immediate room "clean down".

2. Provide a convenient ~~[illegible]~~ disposal route for contaminants ~~[illegible]~~ ~~removal~~ from the clean room. This is accomplished by the grating floor and the rough filters located just below. Since it is the nature of particulate matter to settle, the downward flow of air will greatly accelerate particle removal.

3. Large area of filter will give uniform flow of air to eliminate turbulence. Flow rate for this room approx 25 ft/min is approx 2 changes per min. even greater flow can be tolerated.

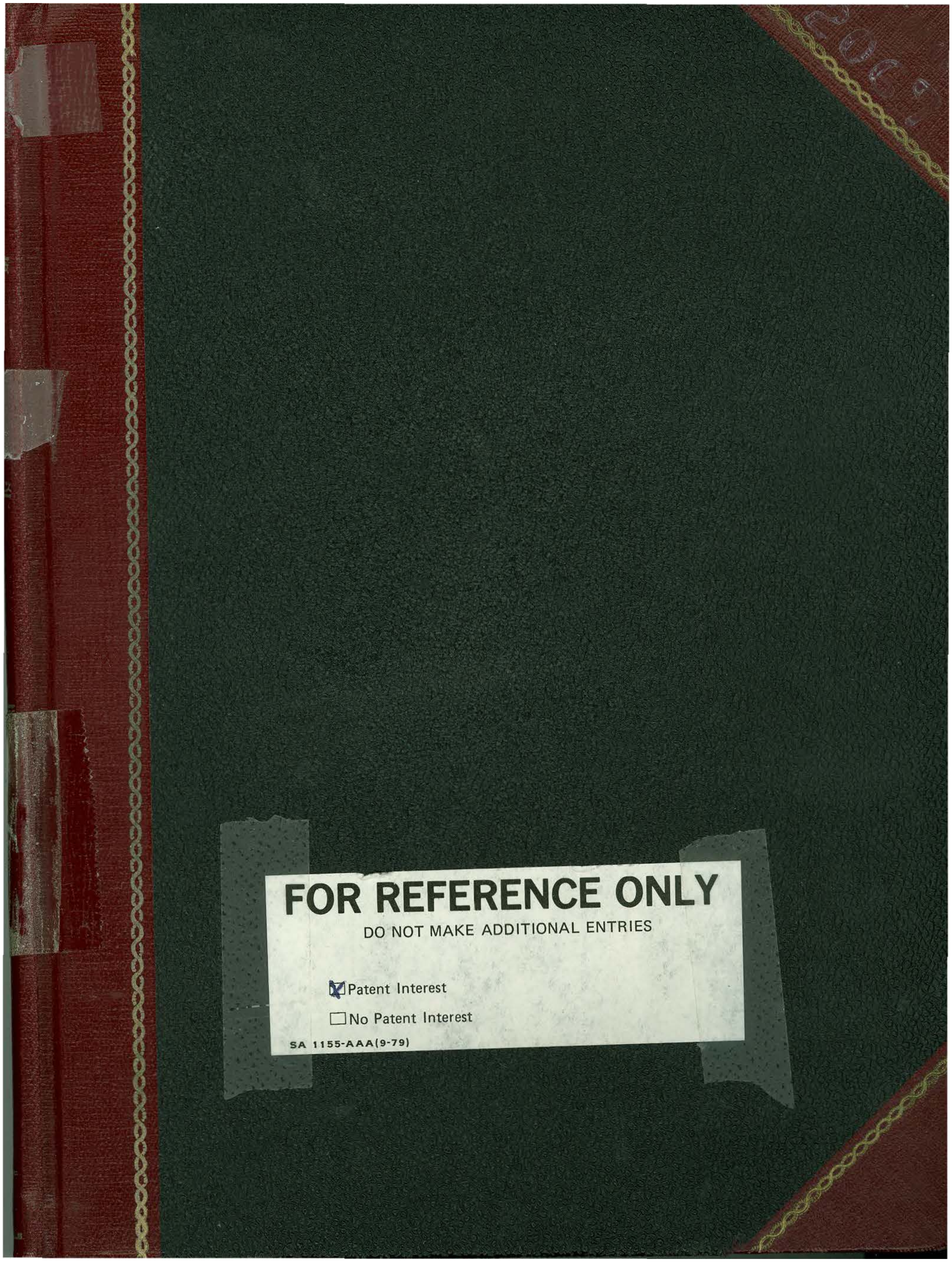
4. The absence of "dead" air spaces in the work area will almost completely eliminate the "settle out" problem.

Cross section of Clean room




INTERIOR - 6' W x 10' L x 7' H

Doors and windows are not shown, since they may be the same as used in present clean room design. No entry air lock is provided or air shower. No need is anticipated except when exterior opening is involved, then an air lock is recommended.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DO NOT MAKE ADDITIONAL ENTRIES
Patent Interest
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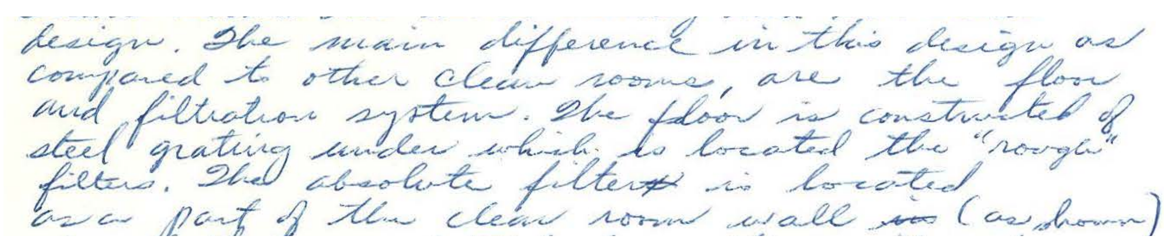
# WHITFIELD’S LAB NOTEBOOK

Whitfield’s laboratory notebook covers work from late 1960 into 1974. He used the notebook to capture ideas and to summarize what he was working on—including writing papers and traveling—as well as his research. It does not offer a detailed exploration of his thinking leading up to technical advances and it only rarely explicates experimental set-ups. It also has long gaps between some entries. It is nonetheless revealing of his approach, his focus, and his results.

The notebook opens with his proposed design for an improved clean room. After extensive research and multiple site visits, Whitfield came up with a simple, but transformative, idea. The innovation was to continually sweep the room with filtered air. This would not only move clean air into the space, but transfer any particles generated by the work or workers out of the space.

On 28 December 1960, Whitfield described the room, listed its advantages, and created a sketch of it. There, on two pages, is the start of a multi-billion-dollar clean room industry, cleaner surgical environments, and the ability to place multiple small integrated circuits on silicon chips. Whitfield called out the key differences between the proposed new design and existing clean rooms as the floor and filtration systems. The air arrives in the room filtered and moves in a consistent flow down and through the floor grating where additional filters capture particulates swept from the room.

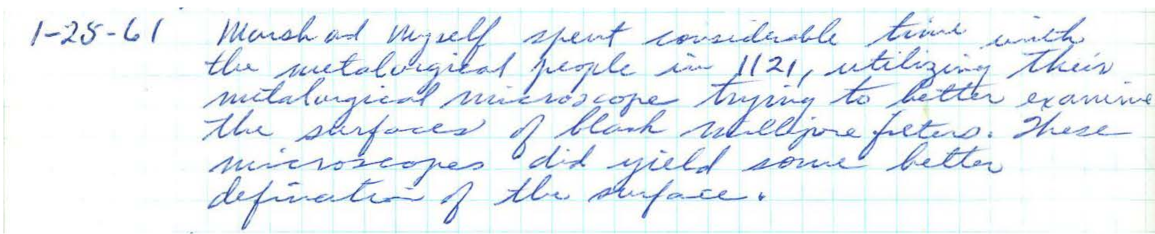

design. The main difference in this design as compared to other clean rooms, are the floor and filtration system. The floor is constructed of steel grating under which is located the "rough" filters. The absolute filters is located as a part of the clean room wall ~~is~~ (as shown)

His initial notebook entry also enumerated the ways the proposed clean room would overcome the disadvantages identified in existing rooms. That list of advantages, as transcribed from the notebook page, reads

1. Provide clean air flow in sufficient quantity and flow patterns to carry contaminants away from clean area and to provide almost immediate room “clean down”.
2. Provide a convenient disposal route for contaminants from the clean room. This is accomplished by the grating floor and the rough filters located just below. Since it is the nature of particulate matter to settle, the downward flow of air will greatly accelerate particle removal.
3. Large area of filter will give uniform flow of air to eliminate turbulence. Flow rate for this room approx 25 ft/min is approx 2 changes per min. even greater flow can be tolerated.
4. The absence of “dead” air spaces in the work area will almost completely eliminate the “settle out” problem. [particulates settling in areas without airflow, to be stirred up by walking or other disturbances]
5. Interviewed years later, Whitfield indicated that the idea was so simple that he could not believe no one had thought of it before. As part of his research, he had Sandia’s legal organization research patents on clean room designs and was surprised that uniformly sweeping air through the room did not appear as part of any of them.

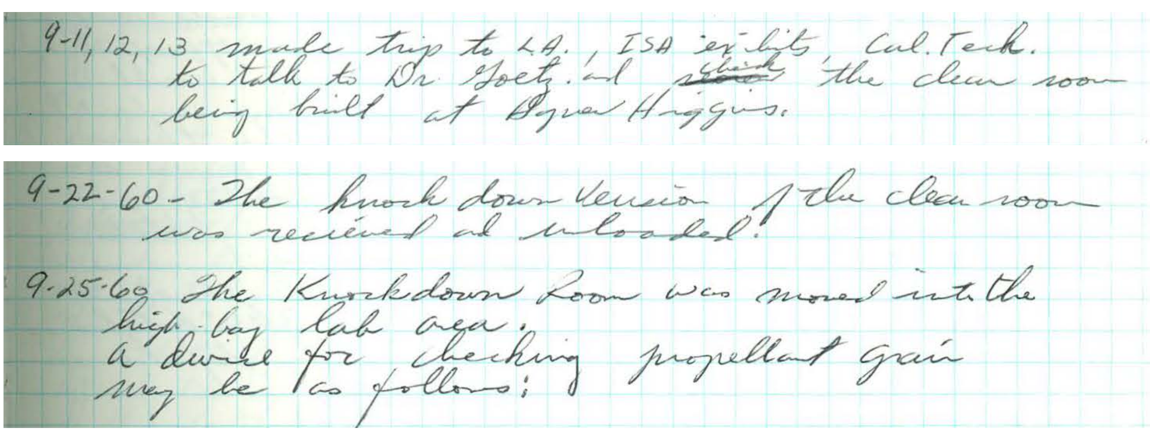
The year following Whitfield's description of the improved clean room design was peppered with activities related to improving the design, getting prototypes built, and working on contamination monitoring and standards.

Within Sandia, the team established dust monitoring methods to compare clean room cleanliness and decided on the smallest particle size to count in those comparisons. Whitfield and Marsh explored methods for examining the surfaces of different filters. They availed themselves of the microscope used by Sandia's metallurgical group and compared different filter types, determining pore size and surface smoothness. This effort was focused on determining the best filters to use in testing to capture and count particles during dust monitoring.



1-25-61 Marsh and myself spent considerable time with the metalurgical people in 1121, utilizing their metalurgical microscope trying to better examine the surfaces of blank millipore filters. These microscopes did yield some better defination of the surface.

During 1961, Sandia contracted with Agnew-Higgins, Inc., of Los Angeles to build a portable prototype of Whitfield's design. Agnew-Higgins was an established manufacturer of clean rooms and worked closely with Whitfield to produce the new design. Whitfield visited the Agnew-Higgins site in September to check on the construction and the room was delivered later in the month.



9-11, 12, 13 made trip to L.A., ISA exhibits, Cal. Tech. to talk to Dr. Goetz and check the clean room being built at Agnew Higgins.

9-22-60 - The knock down version of the clean room was received and unloaded.

9-25-60 The Knockdown Room was moved into the high-bay lab area.
A device for checking propellant grain may be as follows:

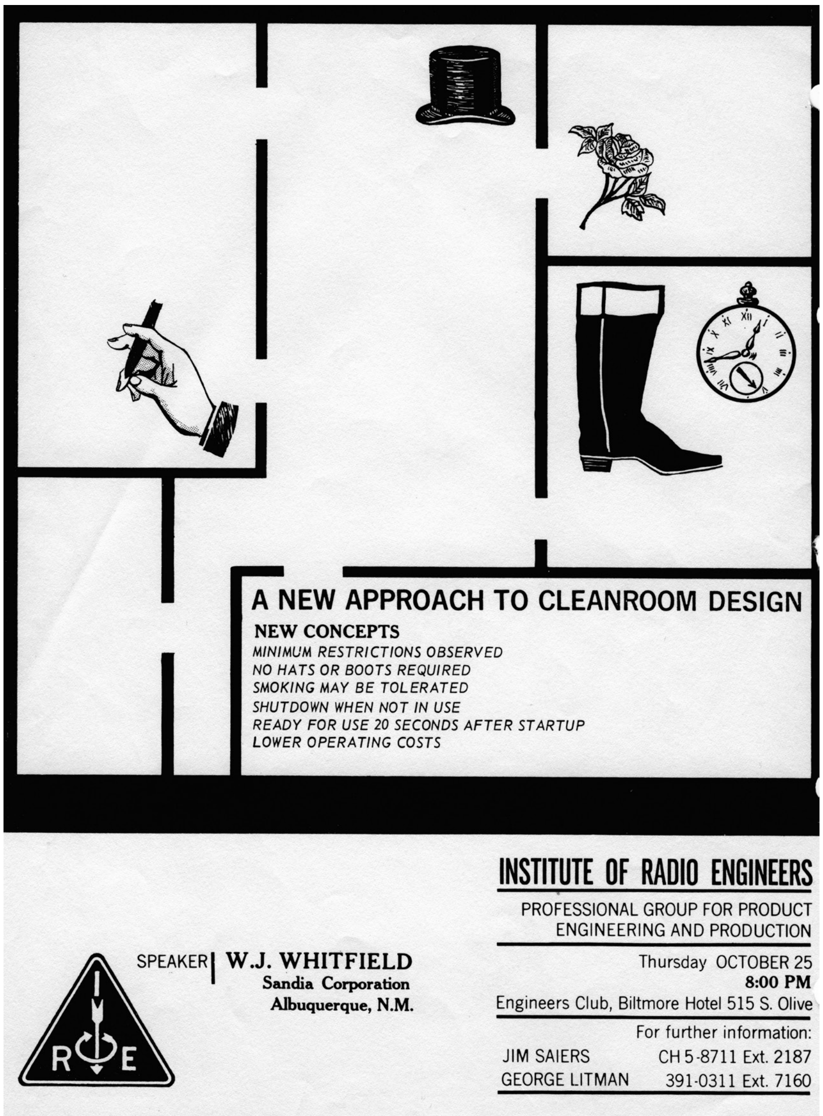
*Notebook entries from September 1961, including notes regarding the construction of the clean room prototype. Note that the last two entries are misdated—they are from 1961, as the earlier entries on the page indicate.*

In November 1961, the prototype (the Knockdown Room referenced in Whitfield's earlier entries) was fully operational. It was a 10' long x 6' wide x 7' high space holding a single work bench. HEPA filters extending to the ceiling formed the wall behind the bench and the room floor was metal grating. Filtered air entered the room through the wall behind the work bench and swept through the space, exited through the floor grate where filters captured any particulates, and recirculated back through the wall filters to re-enter the room.
Early concerns that the constantly moving air would irritate workers in the space were allayed by the actual rate of movement. The air moved at about 1 mph, resulting in about 10 changes of air per minute. Someone walking through a room would experience similar air movement—that is, it was barely noticeable to individuals working in the space.

Data collected on the prototype indicated that the room contained an average of 750 dust particles .3 microns in size or larger per cubic foot of air. The room was approximately 1000 times cleaner than rooms in use at the time. Based on that data, Sandia issued its first press release on the ultra-clean room design in January 1962.

*Bill Neitzel and Willis Whitfield in the prototype clean room, 1961*

The new clean room design caught on quickly. Picking up on Sandia's press release, industry journals detailed the invention and its incredible improvement on existing clean room designs. The March 1962 issue of *Plant Engineering Magazine* included the article "New Ultra-Clean Room Outfilters Them All." *Time* magazine also picked up the news, publishing "Mr. Clean" about Whitfield's achievement in its 13 April 1962 issue.

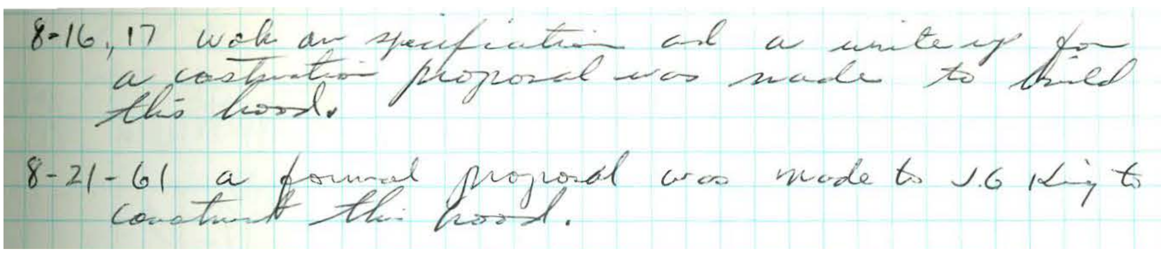



*Advertisement for Whitfield's talk at the Institute of Radio Engineers, touting the advantages of the new clean room design*

Whitfield presented his first technical paper on the design at the National Meeting of the Institute of Environmental Sciences in Chicago in April 1962. The reaction was a combination of incredulity and great excitement. Excitement won. Whitfield was invited to multiple conferences, ultimately giving the presentation from Chicago twenty times. It was also published in the IES Proceedings 1962 as "A New Approach to Cleanroom Design."

Industry leaders like RCA, General Motors, Western Electric, and Bell Labs quickly recognized the potential of the new design and began installing and testing it. Their results were positive and the new clean room was installed in manufacturing plants across the country. Whitfield defined the specifications for the portable, knockdown version of the clean room; he and Marsh were sent to train workers on using the clean bench and developed a manual for it.

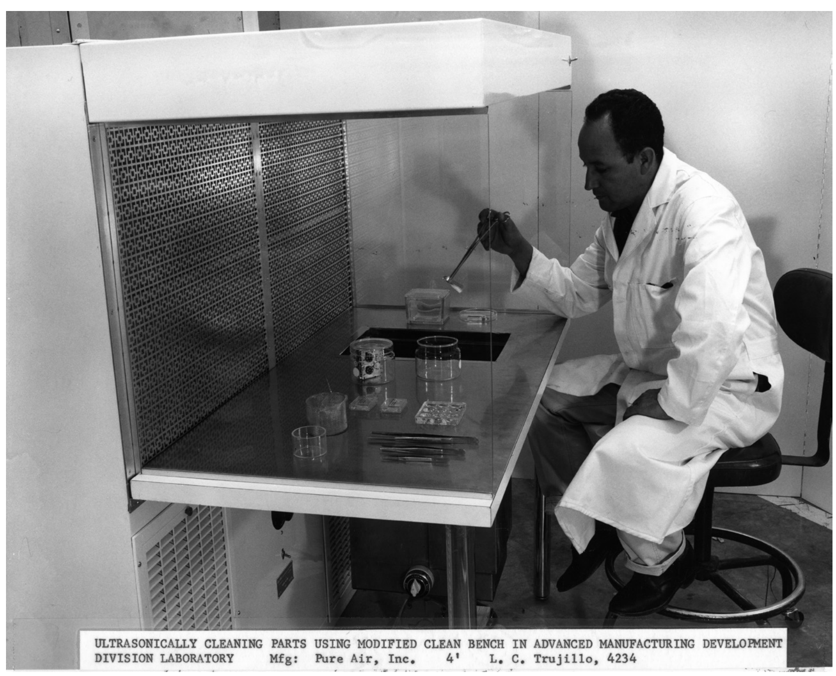
The team also developed a proposal for a clean hood. Whitfield's notebook indicates that the design was submitted to J. Gordon King, supervisor of the advanced manufacturing development section, in August 1961. King's section included Whitfield, Marsh, Neitzel, and Mashburn. King approved the proposal for the clean hood and it was developed, with a prototype in place by March 1962.


8-16, 17 work on specification and a write up for a construction proposal was made to build this hood.

8-21-61 a formal proposal was made to J.G King to construct the hood.

*Entries from page 23 of the notebook indicating that a proposal was submitted for a clean room hood design*

Applying the hood design, Sandia pursued a stand-alone clean bench or work station, developed and assembled by Neitzel, Mashburn, and Trujillo. This was a partially enclosed work bench with a curtained flow down unit that could maintain an atmosphere essentially free of airborne particles when it was operated in an uncontrolled area. Affordable, movable, and easy to install, the bench was as successful as the room.

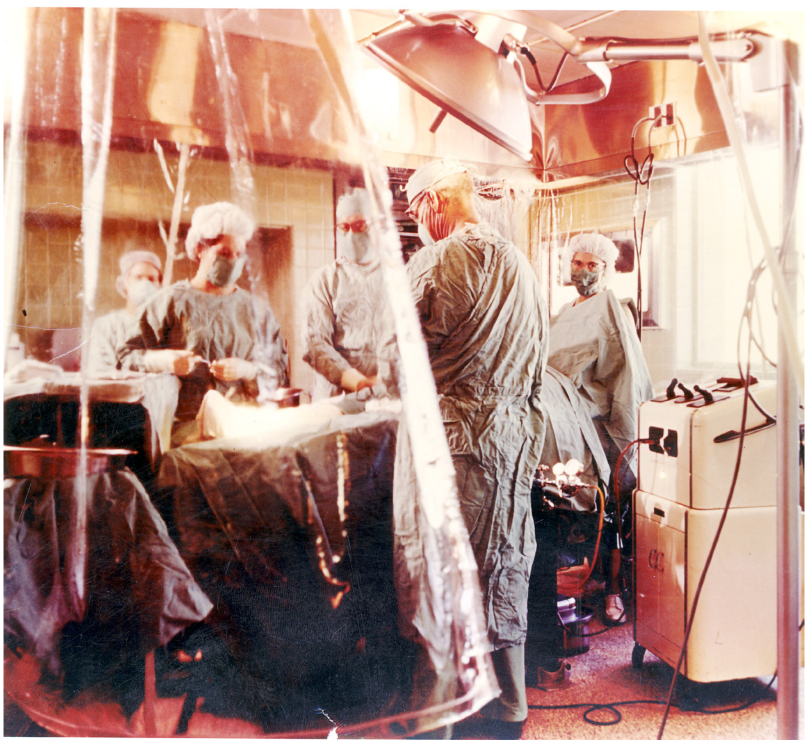



*Longinos Trujillo demonstrates cleaning tools at a modified work bench in the 1960s*

# THE CLEAN ROOM'S IMPACT

Different segments of industry took an interest. Early in 1962, Dr. Randy Lovelace of the Lovelace Clinic in Albuquerque inquired about the possibility of using the clean room in operating rooms. Lovelace worked with Sandia in testing the clean room to reduce bacterial contamination in a conventional operating room while studying the role of airborne bacteria in post-operative wound infections.

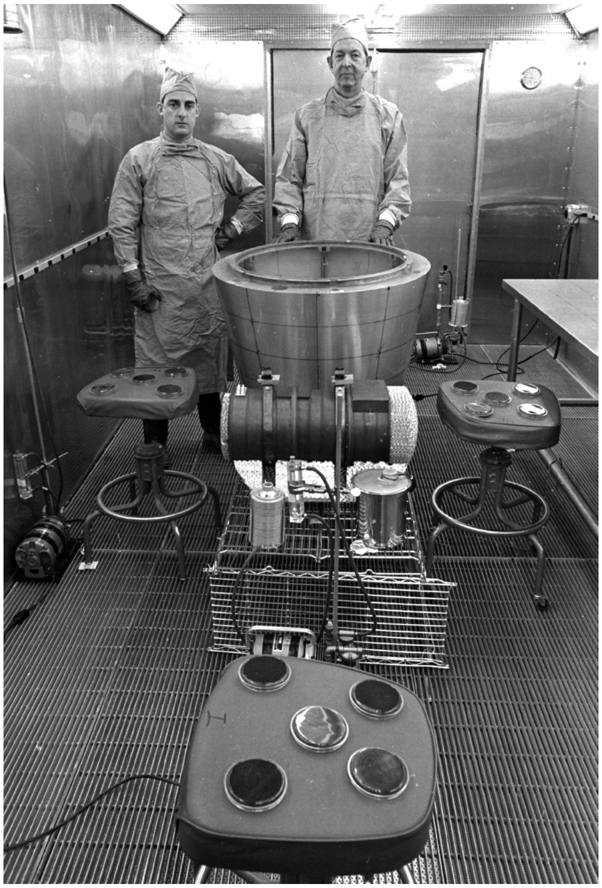
The first hospital operating room using the new design became operational in January 1966 at Bataan Memorial Methodist Hospital (adjacent to the Lovelace Clinic). The design included a filtered ceiling with an air chamber above it, and a clear vinyl curtain reaching from the ceiling to within 30" of the floor. The curtain formed a 12' x 10' operating area. Filtered air flowed straight down inside the curtained area, removing contamination as it went.



*Laminar flow surgical unit, Bataan Memorial Methodist Hospital, Albuquerque, 1966*

By the end of 1962, more than twenty manufacturers were licensed to construct and market clean benches and clean rooms. Pharmaceutical companies were installing clean benches and hoods. NASA requested assistance in establishing clean room requirements and planning for use of clean rooms in the space program. The Atomic Energy Commission filed a patent application on the laminar air flow clean room in Whitfield's name. On 24 November 1964, Patent No. 3,158,457, Ultra-Clean Room, was issued.

In 1963, Sandia and NASA completed a study of the potential of assembling U.S. spacecraft in laminar flow clean rooms to ensure that the craft would not carry contaminants to other planets. Based on the positive outcome of the initial study, the project was undertaken. The study set the pattern that established international standards of planetary quarantine.

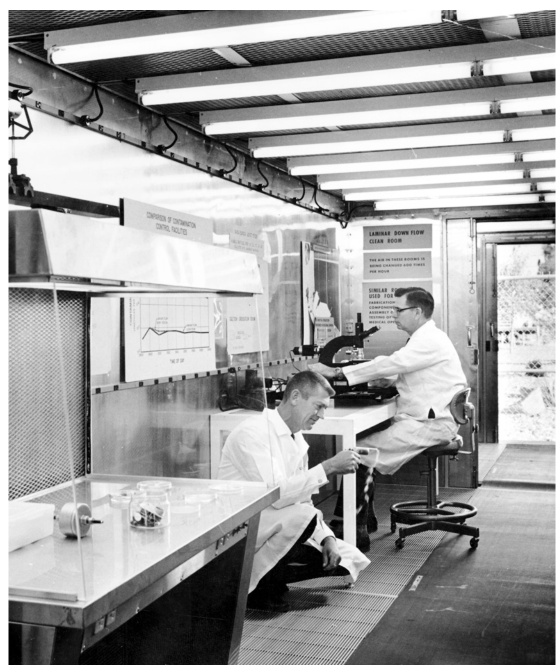


*Inside a Sandia clean room in 1965, Ed Powers of NASA and Vernon Arnold inspect the sterilization of an interplanetary lander*

At its own request, in 1963 Sandia also received an assignment to prepare a Federal Standard for clean rooms. The goal was to introduce common standards and language into the contamination-control industry. Whitfield was involved, as were King and Marsh.

Sandia, the General Services Administration (GSA), the Air Force, the Defense Atomic Support Agency (DASA)[2], and several industrial firms sponsored a conference in Albuquerque to consider a proposed clean room standard. Prior to the meeting, Sandia and DASA personnel drafted a proposed standard for the meeting to consider. After the meeting, a working group met and completed the final standard.

Designated Federal Standard No. 209 and published by GSA in December 1963, the standard defined Whitfield's unidirectional air flow systems as Laminar Air Flow systems. It defined terms and standards for monitoring contamination and advised on clean room upgrades. It also established three classes for environmental control—the Class 100, Class 10,000, and Class 100,000 clean rooms—with defined levels of particles allowed within each class. The laminar air flow room or work station was the only Class 100 facility at the time.



*Bill Neitzel and Jim Mashburn working in a Sandia clean room, 1964*

2 A successor to the Armed Forces Special Weapons Project, DASA was the immediate predecessor of the Defense Nuclear Agency, which eventually became the Defense Threat Reduction Agency.

# THE CLEAN ROOM AND NUCLEAR WEAPONS

The clean room's most important immediate impact from Sandia's point of view was that its suppliers installed clean bench lines and the problems of 1959 were over. Sandia worked closely with U.S. Gauge, the manufacturer that had discovered the original problem with contaminants in manufacturing electromechanical switches. Together, they studied the contamination problem, the clean rooms in use, and tried out potential solutions. Once Whitfield's design was available, U.S. Gauge and other suppliers quickly adopted the new clean room technology and weapons production continued.

*Bulova Watch Company workers at clean bench, 1962. Bulova—making precision timers—was the first of Sandia's supplier to adopt the new clean bench technology.*

Beyond solving the initial problem, the clean room also had a transformative and lasting impact on weapon design and production. Whitfield's development coincided with the introduction of integrated circuits into electronics design and manufacturing. Based on breakthroughs by Jack Kilby at Texas Instruments, Robert Noyce and Jean Hoerni at Fairchild Semiconductor, and Kurt Lehovec of Sprague Electric Company, the first functional semiconductor integrated circuit was introduced in 1960.

Within the world of nuclear weapons, where space was at a premium in the final product, integrated circuits offered the potential to create complex, high-reliability components in smaller, lighter packages. However, manufacturing silicon wafers with multiple transistors in ever narrower spaces required a very clean environment—the smallest particle of dust could ruin an entire chip. Successful nuclear weapon component manufacturing quickly became dependent on the improved clean room.

In the late 1950s and early 1960s, Sandia also pursued active investigations of radiation-hardening for components and weapon sub-systems. To ensure nuclear weapons would operate correctly in radiation environments—including from other nuclear weapons detonating around them—Sandia designed and tested components in test facilities simulating such environments. Components using the new microelectronic circuits were tested along with every other part.

Sandia is now a leader in developing radiation-hardened integrated circuit technologies and components for space and man-made environments. That excellence was achieved because Sandia needed radiation-hardened, complex integrated circuits with high reliability for nuclear weapon designs. Commercial manufacturers were not interested in building or modifying facilities to accommodate the small batches the nuclear weapons complex needed. Sandia chose to create an in-house capability and was manufacturing radiation-hardened microelectronics for weapons systems by the mid-1970s. It then established the Center for Radiation-Hardened Microelectronics, maintaining and expanding its expertise and manufacturing capacity since.

In 1988, Sandia built its Microelectronics Development Laboratory, incorporating advanced clean room technology based on Whitfield's original design. The capability kept expanding to meet design needs, adding wafer manufacturing, compound semiconductor fabrication, electronic circuit manufacturing, and microelectromechanical systems production (MEMS). Research and manufacturing facilities were expanded in the Microsystems and Engineering Sciences Applications (MESA) construction project, which ended in 2007 with state-of the-art clean room facilities in place to house both silicon and microsystems manufacturing.

The microsystems created in MESA extend the processing capabilities of integrated circuits—adding sensing, actuation, and communication functions, for example—within a single package. Chips can embody sensors, photonics, and MEMS components. Advanced packaging technologies allow for custom configurations to suit the precise national security need specified by designers.

This all happens in clean rooms that are direct descendants of Whitfield's knockdown prototype from 1961. In these clean rooms, any particle can ruin a chip, so workers enter the rooms fully covered in clean room garments. They enter through airlocks to keep contaminants out. Once inside, however, the air moves in the familiar sweep Whitfield specified, continually cleaning the room.

# EPILOGUE

In 1992, Sandia presented a plaque of appreciation to the U.S. Gauge Division of Ametek, Inc., in Sellersville, Pennsylvania. Presented by Sandia employee Ned Godshall, the plaque expressed "appreciation of the collaboration between U.S. Gauge and Sandia Laboratories during the late 1950's and early 1960's...," which "resulted in the successful development and production of critical electromechanical components for Sandia systems and led to the invention of the 'Laminar Flow Clean Room' by Sandian Willis Whitfield." Whitfield first visited U.S. Gauge in 1959. Godshall grew up in Sellersville and knew of the clean room improvements from his father, an employee of U.S. Gauge. By 1992, he was working in Sandia's Microelectronics Development Laboratory and actively participated in efforts to acknowledge the connection between Sandia and U.S. Gauge.

Willis Whitfield retired from Sandia in 1984 after a 30-year career of investigation and innovation. The Atomic Energy Commission and the Department of Energy obtained three patents in his name—for the invention of the Ultra Clean Room (issued in 1964), the Laminar Flow Air Hood Apparatus (issued in 1966) and the Solids Irradiator (issued in 1979).

Whitfield is widely celebrated for his achievements, most notably the laminar flow clean room design that transformed manufacturing, medicine, food handling, and silicon chip manufacturing. Within Sandia, his accomplishments are permanently recognized in a sculpture in the courtyard of the Microsystems and Engineering Science Applications (MESA) facilities.

Beyond Sandia, Whitfield was the first person to be placed in the Clean Room Hall of Fame by *Clean Room Magazine* and received the Holley Medal from the American Society of Mechanical Engineers for the unique concept of the laminar flow clean room principle to eliminate airborne contamination in closed spaces. In 1971, he received an honorary doctorate from Hardin-Simmons University. In 2014, he was posthumously inducted into the National Inventors Hall of Fame.

Willis Whitfield died November 12, 2012.

For more information about Whitfield, the clean room, or the history of Sandia National Laboratories, please contact:

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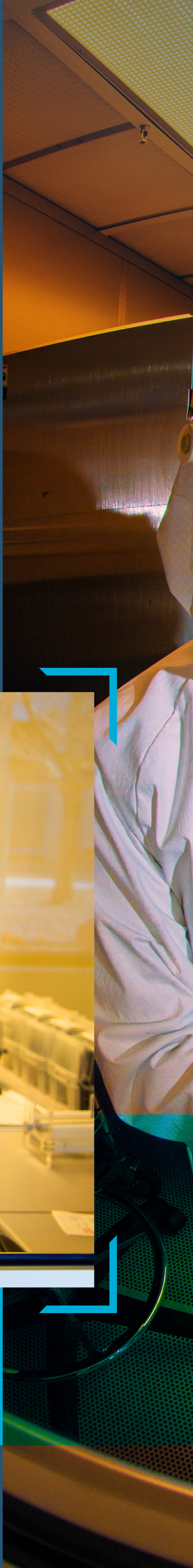

Sandia National Laboratories

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